

RELATION BETWEEN GLOBULAR CLUSTERS AND SUPERMASSIVE BLACK HOLES IN ELLIPTICALS AS A MANIFESTATION OF THE BLACK HOLE FUNDAMENTAL PLANE

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ABSTRACT

We analyze the relation between the mass of the central supermassive black hole (M_{BH}) and the number of globular clusters (N_{GC}) in elliptical galaxies and bulges as a ramification of the black hole fundamental plane, the theoretically predicted and observed multi-variable correlation between M_{BH} and bulge binding energy. Although the tightness of the M_{BH} – N_{GC} correlation suggests an unlikely causal link between supermassive black holes and globular clusters, such a correspondence can exhibit small scatter even if the physical relationship is indirect. We show that the relatively small scatter of the M_{BH} – N_{GC} relation owes to the mutual residual correlation of M_{BH} and N_{GC} with stellar mass when the velocity dispersion is held fixed. Thus, present observations lend evidence for feedback-regulated models in which the bulge binding energy is most important; they do not necessarily imply any ‘special’ connection between globular clusters and M_{BH} . This raises the question of why N_{GC} traces the formation of ellipticals and bulges sufficiently well to be correlated with binding energy.

Subject headings: black hole physics—galaxies: evolution—galaxies: formation—galaxies: elliptical and lenticular, cD

1. INTRODUCTION

There are now well-established correlations between the mass of supermassive black holes (SMBHs) and properties of their host galaxies, such as bulge luminosity, mass, light concentration, and velocity dispersion (Kormendy & Richstone 1995; Magorrian et al. 1998; Ferrarese & Merritt 2000; Gebhardt et al. 2000; Tremaine et al. 2002; Marconi & Hunt 2003; Gültekin et al. 2009). This suggests that the physical mechanism driving growth of the SMBH also plays a key role in forming the bulge (for spiral galaxies) or galaxy (for ellipticals). Analytical estimates (Silk & Rees 1998; Burkert & Silk 2001; Hopkins & Hernquist 2006), as well as numerical simulations (Di Matteo et al. 2005; Springel et al. 2005; Cox et al. 2006; Robertson et al. 2006; Croton et al. 2006; Johansson et al. 2009) with simple prescriptions for SMBH accretion have demonstrated the plausibility of this inference by matching the expected slopes of these correlations.

Regardless of the detailed feedback prescription, these models predict that SMBHs grow until reaching some critical mass, where the energy and/or momentum released by feedback expels material from the nucleus. As such, they robustly predict that the “true” correlation should be between SMBH mass and a quantity such as the binding energy or potential well depth of material in the bulge. Hopkins et al. (2007a) show that the observed correlations with different variables, and importantly their scatter and systematic deviations from the relations, can be understood as the projections of a single fundamental dependence. This relation is approximated closely by a multi-variable correlation, a black hole fundamental plane (BHFP). Aller & Richstone (2007)

confirmed this in a sample of ellipticals and spiral bulges using dynamical models of bulge potentials, and Feoli & Mancini (2009) did so with simple proxies such as $M_{BH} \propto E_b \sim M_* \sigma^2$.

Additional correlations have been found between SMBH mass and dark matter halo mass, as well as the number N_{GC} of globular clusters (GC) in the host galaxy (Spitler & Forbes 2009; Burkert & Tremaine 2010; Harris & Harris 2010). In particular, Burkert & Tremaine (2010, hereafter BT10) argued that N_{GC} is a better predictor of M_{BH} than the velocity dispersion σ , citing a smaller intrinsic scatter and a residual correlation between N_{GC} and M_{BH} in elliptical galaxies even after accounting for the median $M_{BH} - \sigma$ correlation, suggesting a fundamental link between the accretion of gas by the SMBH and the formation of a galaxy’s globular cluster system. Harris & Harris (2010, hereafter HH10) extended the sample by making reasonable estimates of N_{GC} from the literature in galaxies with M_{BH} measurements.

In this letter, we illustrate that the above link can be understood as a consequence of the BHFP relation combined with a residual correlation between N_{GC} and the bulge’s stellar mass M_* at fixed σ . Rather than suggesting a single “best” correlation between M_{BH} and a single galaxy parameter, the BHFP implies that the best predictor of SMBH mass is some combination thereof. For example, M_{BH} has a positive correlation with the bulge’s stellar mass even at fixed σ . Although the number of globular clusters in a particular galaxy, like M_{BH} , is a complex function of the galaxy’s formation history, there exists a similar positive residual correlation between N_{GC} and M_* , so that the resulting N_{GC} – M_{BH} residuals (fixing σ) will be positively correlated.

In §2 we describe a sample of 32 elliptical galaxies from Peng et al. (2008) with auxiliary data compiled in Hopkins et al. (2008b, and subsequent papers). In §3 we fit separately the relations M_* – σ and N_{GC} – σ in

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these galaxies to establish the residual correlation between N_{GC} and M_* . Then we combine this residual slope with knowledge of the M_{BH} – M_* correlation at fixed σ from the BHFP, and calculate the residual correlation and scatter expected between N_{GC} and M_{BH} . We summarize and conclude in §4.

2. THE DATA

To determine the dependence of N_{GC} on M_* at fixed σ , we cross-match objects compiled in Hopkins et al. (2008b) and subsequent works with the ACS Virgo Cluster Survey (VCC, Côté et al. 2004), from which Peng et al. (2008) determined globular cluster counts (N_{GC}) and uncertainties. Following BT10, we obtained N_{GC} for several additional galaxies from Spitler et al. (2008).

We obtained stellar masses and uncertainties from Peng et al. (2008) and Hopkins et al. (2009a,b), who compiled photometric data from several authors (e.g. Bender et al. 1988; Rothberg & Joseph 2004; Lauer et al. 2007; Kormendy et al. 2009, and references therein). We use velocity dispersions as compiled by Hopkins et al. (2009a,b). The latter quantity is the one best-determined for nearby massive galaxies, so we assume a log-uniform uncertainty in σ of 0.02 dex, consistent with literature values. This approach yields 33 galaxies for which we will determine the residual correlation between N_{GC} and M_* . We discard the known recent merger remnant NGC1316 because its nuclear velocity dispersion is unrelaxed and the globular cluster system is actively evolving (Schweizer 1980). The galaxy properties used to analyze this 32-galaxy sample are provided in Table 1.

In addition, we will utilize the M_{BH} , N_{GC} , and σ data directly from Table 1 of BT10 (compiled mostly from Gültekin et al. (2009)), and the M_{BH} , N_{GC} data from Table 1 of HH10. For the latter, we use the mean recorded σ values from the Hyperleda database (Paturel et al. 2003; McElroy 1995). These two sources yield 21 galaxies that serve as a combined comparison sample (Table 2) for our derived M_{BH} – N_{GC} residual correlation. We note that BT10 and HH10 use slightly different, but statistically consistent, values for N_{GC} where the samples overlap. The differing values of M_{BH} may make a larger difference in cases where multiple measurements exist; here, we follow BT10 and give half weight to each in our fits. Furthermore, different studies provide different values for the velocity dispersion of a given galaxy; for example, Hyperleda returns σ values ~ 10 – 20 km/s smaller than the ones from BT10, and the papers by Hopkins et al. provide values that differ by $\sim \pm 10$ – 20 km/s. We computed the observed residual N_{GC} – M_{BH} correlation using these alternate sources of σ , and find that the small changes this introduces leave our conclusions completely unchanged.

3. CORRELATIONS

Both the BHFP and M_{BH} – N_{GC} relation appear to perform better than the M_{BH} – σ relation because they explain its residuals and hence have a smaller intrinsic dispersion. Rigorously, this can be restated as follows: at fixed σ , the residuals in M_{BH} correlate tightly with the residuals in N_{GC} and in M_* for the BHFP.

The question then arises: does N_{GC} directly explain

the residuals in M_{BH} , or could the latter be attributed to other variables already proposed? Specifically, we examine whether the observed N_{GC} – M_{BH} relation is predicted as an indirect consequence of the BHFP relation. This is motivated by the BHFP prediction that at fixed σ , good tracers of the bulge binding energy correlate tightly with the residuals in M_{BH} . (Interestingly, a similar relation was shown for the binding energies of individual Milky Way globulars by McLaughlin (2000).) An approximation to the bulge binding energy in ellipticals is a quantity like $M_*\sigma^2$, so that at fixed σ , galaxies with larger M_* will have a greater binding energy. Thus, if N_{GC} adequately traces M_* at fixed σ , as might be natural given the observed N_{GC} –galaxy correlations, then the tightness of the N_{GC} – M_{BH} relation is expected.

In this work, we focus on a particular projection of the BHFP that uses the bulge binding energy as the driving parameter. However, we note that the general BHFP, and also the corresponding salient relation for GCs (e.g. Harris & van den Bergh 1981; McLaughlin 1999, and subsequent works) depends on galaxy formation history in a more complicated way (Hopkins et al. 2009c). Thus while the bulge binding energy serves adequately for our purposes, a more detailed accounting of, for example, the total baryon mass may lead to an even tighter expected correspondence.

As follows, we calculate the expected residuals in N_{GC} – M_{BH} assuming that this relation is a consequence of the BHFP and no other physics. As an expression of the BHFP correlation, we use the relation between the mass of the SMBH and bulge binding energy from Hopkins et al. (2007a),

$$\log M_{BH} = \eta + \beta \log(M_*\sigma^2),$$

where $\eta = 8.23 \pm 0.06$, and $\beta = 0.71 \pm 0.06$. We will denote this quantity as predicted from the other observed variables as $\log\langle M_{BH} | \text{BHFP} \rangle$. Then we subtract from this the logarithm of M_{BH} as predicted solely from M_{BH} – σ , denoted by $\log\langle M_{BH} | \sigma \rangle$, to obtain the BHFP-predicted residual correlation between M_{BH} and M_* . We will signify this difference in logarithmic quantities as ΔM_{BH} (ΔM_* , ΔN_{GC}):

$$\begin{aligned} \Delta M_{BH} &= \log\langle M_{BH} | \text{BHFP} \rangle - \log\langle M_{BH} | \sigma \rangle = \\ &= \beta \log(M_*\sigma^2) - \beta \log(\langle M_* | \sigma \rangle \sigma^2) \\ &= \beta(\log M_* - \log\langle M_* | \sigma \rangle) = \beta \Delta M_*. \end{aligned} \quad (1)$$

This is just the statement that at fixed σ , $M_{BH} \propto M_*^\beta$.

If there exists a relation between ΔN_{GC} and ΔM_* :

$$\Delta N_{GC} = \gamma \Delta M_*, \quad (2)$$

this will therefore result in a correlation between ΔN_{GC} and ΔM_{BH} :

$$\Delta N_{GC} = \frac{\gamma}{\beta} \Delta M_{BH} = \alpha \Delta M_{BH}. \quad (3)$$

To test this, we first calculate γ from the existing data to establish a correlation between N_{GC} and M_* at fixed velocity dispersion σ (Figure 1), and then combine it with the BHFP to create a prediction for the N_{GC} – M_{BH} residuals. Then, in Figure 2, we compare this prediction to the observed residual correlation between N_{GC} and M_{BH} from BT10 and HH10.

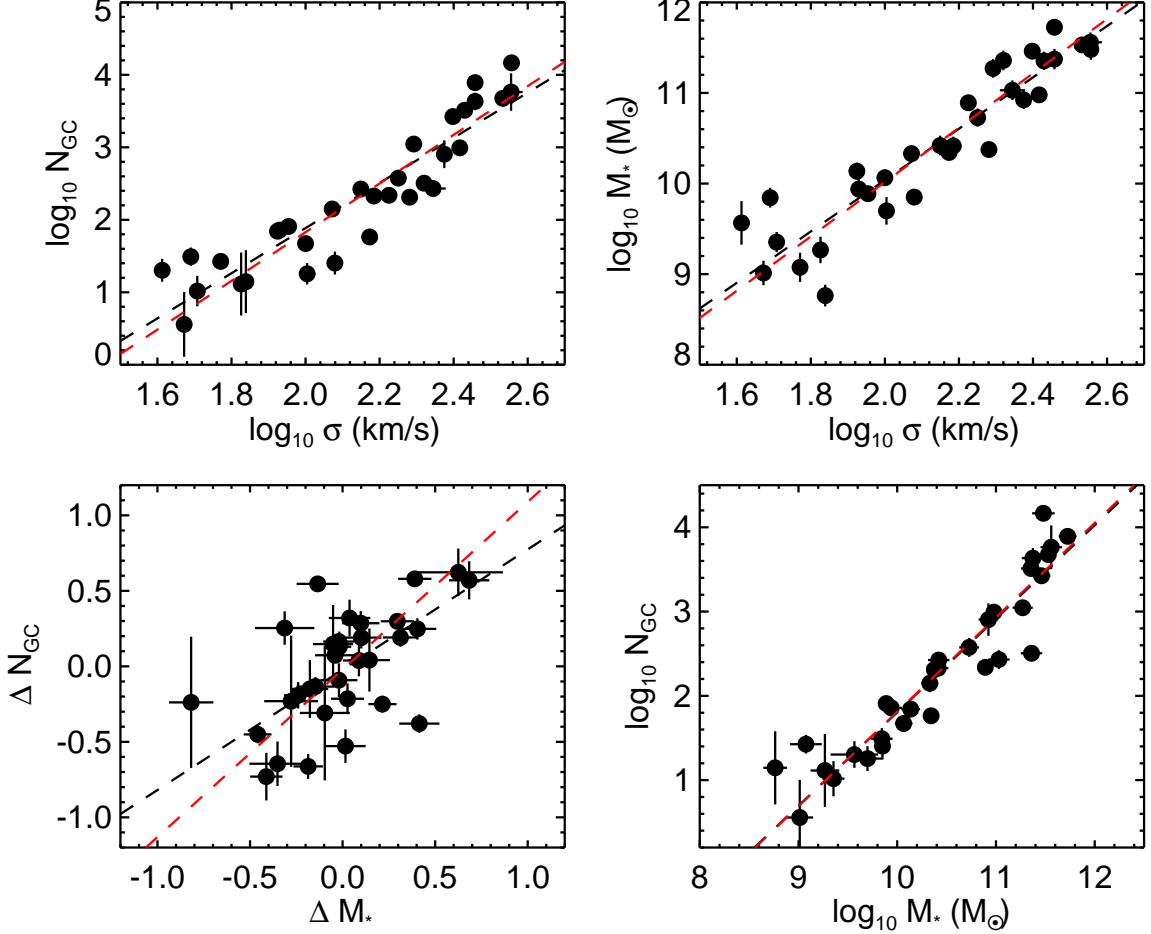


Figure 1. *Top:* Observed correlations of N_{GC} and M_* with velocity dispersion σ for the 32-galaxy sample described in §2. *Lower Left:* Correlation between N_{GC} and M_* at fixed σ : ΔN_{GC} (ΔM_*) is the difference between the observed logarithm of N_{GC} (M_*) and the expected value of the logarithm of N_{GC} (M_*) given the linear relation in the top left (top right) panel. The lines are our regression curves fitted to the data. The dashed black curves are fitted using a χ^2 technique accounting for intrinsic scatter (Tremaine et al. 2002), while the dashed red curves use an alternative maximum-likelihood technique from Akritas & Bershady (1996). There is a clear positive correlation between ΔN_{GC} and ΔM_* . If the BHFP is the true underlying relation, then this observed residual correlation will lead to a correlation between N_{GC} and M_{BH} , even at fixed σ and with no other physics linking M_{BH} to the globular cluster systems. *Lower Right:* The observed correlation between N_{GC} and M_* .

Specifically, we begin by determining the observed best-fit linear correlations between $\log N_{GC}$ and $\log \sigma$, and $\log M_*$ and $\log \sigma$. The resulting fits are shown in the top two panels of Figure 1. We undertake all fits using two methods: the χ^2 -minimization methods of Tremaine et al. (2002) (hereafter, T02), and the bivariate correlated errors and intrinsic scatter (BCES) estimators of Akritas & Bershady (1996). For the former, we account for intrinsic scatter in the Y axis by adding a uniform scatter in quadrature with the measurement errors such that the reduced- χ^2 value of the fit is 1. For the latter, we choose the regression line that bisects the BCES(Y|X) and BCES(X|Y) curves. Altering these choices leads to small changes in the residual values, but does not change the residual slope in a statistically significant way. One-sigma uncertainties in the fitted slopes are calculated using paired nonparametric bootstrap simulations (Babu & Rao 1993).

For each object, we then use the fitted relation to compute the expected value of $\log N_{GC}$ ($\log M_*$) given its observed value of σ , and subtract it from the observed value of $\log N_{GC}$ ($\log M_*$) to obtain ΔN_{GC} (ΔM_*). In

the lower left panel of Figure 1, as expected we see a clear positive correlation between ΔN_{GC} and ΔM_* , indicating that at a fixed σ , elliptical galaxies with more globular clusters also have a larger total stellar mass. We note that the values of ΔN_{GC} and ΔM_{BH} calculated using BCES or χ^2 -minimization on the direct correlations are the same to within 0.1 dex. Subsequent estimates of the residual slope are unaffected by this choice.

However, the two fitting methods obtain somewhat different estimates for the slope of the resulting residual correlation, γ , which we will use to estimate the expected N_{GC} – M_{BH} residual slope $\alpha = \gamma/\beta$. As plotted in Figure 1, we find

$$\begin{aligned}\gamma_{T02} &= 0.79 \pm 0.25 \\ \gamma_{BCES} &= 1.11 \pm 0.21,\end{aligned}$$

and correspondingly,

$$\begin{aligned}\alpha_{T02} &= 1.11 \pm 0.36 \\ \alpha_{BCES} &= 1.56 \pm 0.32.\end{aligned}$$

In Figure 2, we compare this predicted slope with the

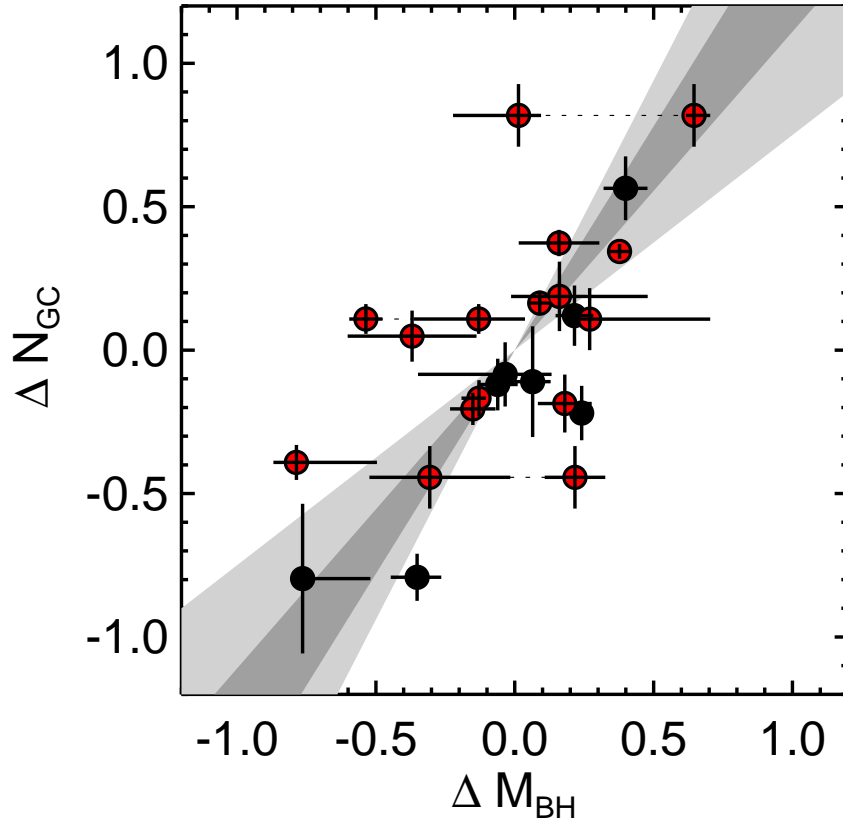


Figure 2. Residual correlation between N_{GC} and M_{BH} at fixed velocity dispersion σ . The points are data from BT10 and HH10; we follow BT10 where multiple M_{BH} measurements exist by assigning each measurement half weight in any fits. Red points correspond to the BT10 sample; their positions here and in BT10’s Figure 3 differ slightly because we take N_{GC} residuals with respect to σ instead of bulge luminosity, but the residuals here have roughly the same slope and span a similar range of ΔN_{GC} as compared with BT10. The eight points added by the elliptical sample of HH10 reinforce this residual correlation and expand its range. The dark gray shaded region is the *predicted* residual correlation (with associated 1-sigma uncertainty in lighter shade) assuming that M_{BH} is determined only by the BHFP, combined with the observed correlation between N_{GC} and M_* at fixed σ determined by fitting the data in Figure 1. We see that the observed residual slope is in good agreement with this expected slope. Thus the apparent additional predictive power of N_{GC} for M_{BH} can be entirely accounted for by the predicted correlation of M_{BH} and the observed correlation of N_{GC} with the bulge binding energy.

one observed in the comparison sample of BT10 and HH10. Again, we compute the residuals against σ in both N_{GC} and M_{BH} ; note that for consistency, this is slightly different than the quantities plotted in BT10’s Figure 3 where the N_{GC} residual was computed against the bulge luminosity, not velocity dispersion. We plot a region in light gray to highlight the extremes of the predicted slopes, corresponding to the range bounded by the 1-sigma uncertainties in the slope given by our two regression methods. In darker gray we simply plot the range bounded by our two slope estimates.

As in Figure 1, we fit the data directly and find that the observed residual slope between N_{GC} and M_{BH} is

$$\begin{aligned}\hat{\alpha}_{T02} &= 0.78 \pm 0.24 \\ \hat{\alpha}_{BCES} &= 1.33 \pm 0.34,\end{aligned}$$

in good agreement with the BHFP predictions above.

The detection of this residual correlation by BT10 quantitatively demonstrates that N_{GC} is a better predictor of M_{BH} than is σ . Such a comparison can be alternatively phrased as a reduction in the intrinsic scatter of the correlation. In BT10, the intrinsic scatter of $M_{BH}-\sigma$ was found to be $\epsilon \sim 0.3$ dex, while the intrinsic scatter in $N_{GC}-M_{BH}$ is $\epsilon \sim 0.2$ dex. The magnitude of

this dispersion can be predicted by combining the BHFP relation with the observed correlations with N_{GC} . From Hopkins et al. (2007a), we see that the $M_{BH}-E_b$ correlation has an intrinsic scatter $\sim 0.2-0.25$ dex, and from the present data, we find the scatter of E_b-N_{GC} is 0.22 ± 0.04 dex. By propagating these as measurement uncertainties to the $M_{BH}-N_{GC}$ relation, we predict that the measured $N_{GC}-M_{BH}$ intrinsic scatter should be $\epsilon = 0.23 \pm 0.03$ dex, consistent with the measurement by BT10. It is also consistent with the combined dataset of BT10 and HH10, for which we find $\epsilon = 0.21 \pm 0.04$ dex.

4. CONCLUSIONS

We have shown that the number of globular clusters in elliptical galaxies exhibits a residual dependence on M_* at fixed σ , implying that the bulge binding energy ($\sim M_*\sigma^2$) is a better indicator of N_{GC} than σ or M_* alone. The same was shown to be true for M_{BH} by Hopkins et al. (2007a), as these parameters constitute a formulation of the BHFP. Thus the apparent power of $M_{BH}-N_{GC}$ versus $M_{BH}-\sigma$ owes to the fact that N_{GC} and M_{BH} are both tracers of the same fundamental property such as the bulge binding energy.

This resolves several puzzling aspects of the previous interpretation of the data. As BT10 themselves point

out, there cannot be a direct causal correlation between N_{GC} and M_{BH} , since most of the GC mass is at very large radii and has never had any interaction with the galaxy nucleus. Moreover, while most GCs likely formed at very high redshift, the final mass of the SMBH is sensitive to its growth via gas accretion at $z \lesssim 2$ (e.g. Hopkins & Hernquist 2006; Hopkins et al. 2007c, 2008a). However, this naturally predicts that N_{GC} should serve reasonably well as a mass tracer, so that the dependence of M_{BH} on M_* and formation time leads to a surprisingly tight but expected N_{GC} – M_{BH} correlation. The same arguments explain the result in Hopkins et al. (2009c), who show that the observed M_{BH} is sensitive to the entire galaxy baryonic mass – i.e. perhaps the mass traced by N_{GC} is the same as the mass that actually sets the escape velocity and potential well depth at $R = 0$, rather than just the stellar mass enclosed in a small radius around the BH, which can vary widely in systems of similar M_{BH} . Such a relation between N_{GC} and global galaxy mass or luminosity has been demonstrated (e.g. Harris & van den Bergh 1981; McLaughlin 1999), and this trait supports the idea that N_{GC} and M_{BH} are connected indirectly by a more fundamental galaxy property.

This also naturally explains why HH10 find that the relation breaks down for S0 galaxies. These galaxies are structurally different than ellipticals and may have different formation histories (Larson et al. 1980), so N_{GC} and the total stellar mass may not faithfully trace the bulge binding energy. Since S0’s are not particularly discrepant in M_{BH} – σ (e.g. Gültekin et al. 2009, and previous works), this suggests that the N_{GC} –bulge relation is the connection that weakens for these systems. HH10 also find no statistically significant correlation in spirals: although three out of the four spirals from HH10 lie on the N_{GC} – M_{BH} relation, there simply isn’t yet enough data to know for sure if this relation persists for spiral bulges. However, the underlying BHFP relation ties M_{BH} to the binding energy and explains its residual correlations with bulge parameters, even for these disk galaxies where N_{GC} possibly deviates. This alone suggests that the BHFP, not M_{BH} – N_{GC} or M_{BH} – σ , is the ‘more fundamental’ correlation.

Hopkins et al. (2007b) showed that the existence of a black hole fundamental plane is a robust prediction of numerical simulations of gas-rich mergers that include the effects of gas dissipation, cooling, star formation, and black hole accretion and feedback. The present work shows that this local and widely expected correlation between supermassive black hole mass and bulge binding energy in feedback-regulated scenarios, combined with a similar correlation for N_{GC} , can account for the observed N_{GC} – M_{BH} relation and its scatter. The interesting question raised by such a correlation is *not* why N_{GC} correlates tightly with M_{BH} , since this is indirect, but why N_{GC} correlates tightly with galaxy binding energy/potential well depth. Some such correlation is expected and observed (McLaughlin 1999; Blakeslee 1999; Peng et al. 2008): an example is that systems at fixed velocity dispersion with higher stellar mass have accreted or formed more stars, likely including globular clusters. But that the N_{GC} –bulge relation should be so tight, and include both metal-rich and metal-poor populations, may support the inferences by BT10 and HH10 (and refer-

ences therein) that the formation of globular cluster systems and growth of supermassive black holes in elliptical galaxies are driven by a common galaxy property.

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Table 1
Galaxy properties for Figure 1

Galaxy	N_{GC}	M_* ($10^9 M_\odot$)	σ (km/s)
NGC0821	320 ± 45^a	229 ± 57	209 ± 10
NGC1399	5800 ± 700^a	363 ± 91	359 ± 18
NGC3377	266 ± 66^b	26.3 ± 6.6	141 ± 7
NGC3379	270 ± 68^a	107 ± 27	221 ± 11
NGC4318	18 ± 6.1	5.0 ± 1.7	101 ± 5
NGC4365	3246 ± 598	226 ± 52	269 ± 13
NGC4374	4301 ± 1201	236 ± 61	287 ± 14
NGC4382	1110 ± 181	186 ± 44	196 ± 10
NGC4387	69.5 ± 9.8	13.7 ± 3	84 ± 4.2
NGC4406	2660 ± 129	289 ± 60	250 ± 12
NGC4434	141 ± 34	21.4 ± 4	118 ± 6
NGC4458	72 ± 12	8.7 ± 2	85 ± 4.3
NGC4459	218 ± 28	77.9 ± 14	168 ± 8
NGC4464	25.3 ± 9.2	7.1 ± 1.4	120 ± 6
NGC4467	-6 ± 13	1.8 ± 0.6	67 ± 3.4
NGC4472	7813 ± 830	531 ± 110	287 ± 14
NGC4473	76 ± 97	53.5 ± 12	178 ± 9
NGC4476	20.1 ± 7.3	3.7 ± 2	41 ± 2.1
NGC4478	58 ± 11	22 ± 4	149 ± 7
NGC4486	14660 ± 891	302 ± 79	360 ± 18
NGC4489	31 ± 9	6.98 ± 1.7	49 ± 2.4
NGC4515	81 ± 10	7.7 ± 1.5	90 ± 4.5
NGC4551	47 ± 11	11.6 ± 2.4	100 ± 5
NGC4552	984 ± 198	95 ± 16.9	261 ± 13
NGC4564	213 ± 31	26 ± 6	153 ± 8
NGC4621	803 ± 355	83.9 ± 19	237 ± 12
NGC4649	4745 ± 1099	339 ± 50	341 ± 17
NGC4660	205 ± 28	23.8 ± 4	191 ± 9
VCC1199	-9 ± 14	0.58 ± 0.16	69 ± 3.5
VCC1440	26.7 ± 6.8	1.2 ± 0.44	59 ± 3
VCC1627	3.6 ± 3.7	1.0 ± 0.32	47 ± 2.4
VCC1871	10.4 ± 5	2.3 ± 0.58	51 ± 2.6

Note. — Properties of elliptical galaxies used to determine the correlation of N_{GC} with M_* at fixed velocity dispersion σ (Figure 1). Values of N_{GC} and M_* are compiled from Peng et al. (2008) unless otherwise noted. Values of σ are compiled from Hopkins et al. (2009a,b) and assumed to have a log-uniform uncertainty of 0.02 dex.

^a Spitler et al. (2008)

^b Kundu & Whitmore (2001)

Table 2
Galaxy properties for Figure 2

Galaxy	M_{BH} (M_{\odot})	+1-sigma (M_{\odot})	-1-sigma (M_{\odot})	N_{GC}	σ (km/s)	ΔN_{GC}	ΔM_{BH}
Burkert & Tremaine (2010)							
NGC0821	4.2×10^7	2.8×10^7	8×10^6	320 ± 45	209 ± 10	-0.39	-0.79
NGC1316	1.5×10^8	8×10^7	8×10^7	1173 ± 240	226 ± 9	0.05	-0.37
NGC1399	1.3×10^9	5×10^8	7×10^8	5800 ± 700	337 ± 16	0.11	-0.13
	5.1×10^8	7×10^7	7×10^7			0.11	-0.54
NGC3377	1.1×10^8	1.1×10^8	1×10^7	266 ± 66	145 ± 7	0.11	0.27
NGC3379	1.2×10^8	8×10^7	6×10^7	270 ± 68	206 ± 10	-0.44	-0.31
	4×10^8	1×10^8	1×10^8			-0.44	0.22
NGC4374	1.5×10^9	1.1×10^9	6×10^8	4301 ± 1201	296 ± 14	0.19	0.16
NGC4459	7.4×10^7	1.4×10^7	1.4×10^7	218 ± 28	167 ± 8	-0.20	-0.15
NGC4472	1.8×10^9	6×10^8	6×10^8	7813 ± 830	310 ± 10	0.37	0.16
NGC4486	6.4×10^9	5×10^8	5×10^8	14660 ± 891	375 ± 18	0.34	0.38
NGC4564	6.9×10^7	4×10^6	1×10^7	213 ± 31	162 ± 8	-0.17	-0.13
NGC4594	5.5×10^8	5×10^7	5×10^7	1900 ± 189	240 ± 12	0.16	0.09
NGC4649	4.5×10^9	1×10^9	1×10^9	4745 ± 1099	385 ± 19	-0.19	0.18
NGC5128	3×10^8	4×10^7	2×10^7	1550 ± 390	150 ± 7	0.82	0.65
	7×10^7	1.3×10^7	3.8×10^7			0.82	0.01
Harris & Harris (2010)							
NGC2778	1.6×10^7	9×10^6	2×10^5	50 ± 30	162 ± 8	-0.80	-0.76
NGC4261	5.5×10^8	1.1×10^8	1.2×10^8	530 ± 100	309 ± 14	-0.79	-0.35
NGC4473	1.3×10^8	5×10^7	9.4×10^7	376 ± 97	180 ± 8	-0.08	-0.03
NGC4552	4.8×10^8	8×10^7	8×10^7	1200 ± 250	253 ± 12	-0.12	-0.06
NGC4621	4×10^8	6×10^7	6×10^7	800 ± 355	225 ± 11	-0.11	-0.06
NGC4697	2×10^8	2×10^7	2×10^7	229 ± 50	171 ± 8	-0.22	0.24
NGC5813	7×10^8	1.1×10^8	1.1×10^8	1650 ± 400	237 ± 11	0.12	0.22
NGC5846	1.1×10^9	2×10^8	2×10^8	4700 ± 1200	239 ± 11	0.56	0.40

Note. — Properties of elliptical galaxies used to calculate the correlation of N_{GC} with M_{BH} at fixed velocity dispersion σ (Figure 2), following BT10. Data for N_{GC} and M_{BH} are compiled from BT10 and HH10. Values of σ are as presented in BT10 for those galaxies, and values of σ for the HH10 ellipticals are taken as the mean value recorded in the HyperLeda database (Paturel et al. 2003; McElroy 1995).